

DoD-Tailored Environmental Products from Near Real-Time Terra/Aqua MODIS in Support of Operation Iraqi Freedom

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Abstract—The Naval Research Laboratory (NRL) provided pseudo-operational satellite imagery support to Coalition forces during Operation Iraqi Freedom. This paper highlights some of the high quality products from the Moderate Resolution Imaging Spectroradiometer (MODIS) that were developed in response to user-defined needs, and measures taken to host the imagery upon the Satellite Focus Web Page generally within 2.5 hours of data collection.

I. INTRODUCTION

Difficult weather conditions confronted Coalition forces during the early stages of Operation Iraqi Freedom (OIF), at times significantly challenging all varieties of ground, air and sea-based operations. Amidst high winds, brown-out dust storms and strong convective lines, the Meteorology and Oceanography (METOC) Officers of the Naval carrier groups operating in the Northern Arabian Gulf faced the daunting task of coordinating strike operations (including the determination of optimal targets and appropriate weapons selection), navigating rough waters, and minimizing pilot risk. Thanks in part to sensors high above the weather and efforts half a world away to process their observations, Coalition assets were equipped with new capabilities to better characterize, predict, and contend with the harsh weather and responsibilities of the task at hand.

This paper describes measures taken by the Naval Research Laboratory's Marine Meteorology Division, in conjunction with Fleet Numerical Meteorology and Oceanography Center (FNMOC), the National Aeronautics and Space Administration (NASA), and the National Oceanographic and Atmospheric Administration (NOAA) to design, develop, and rapidly prototype a new satellite product resource. The NRL/FNMOC "Satellite Focus Web Page" interface, an online utility leveraging a full complement of operational and research-grade satellites in providing new and innovative value-added products bearing specific relevance to the Department of Defense (DoD) METOC customer, served as the demonstration vehicle. Foremost among the high spatial/spectral resolution telemetries fueling Satellite Focus are the

Moderate Resolution Imaging Spectroradiometers (MODIS; e.g., [1]) carried aboard the Earth Observing System (EOS) Terra and Aqua satellites. Scientists and engineers worked literally around the clock in bringing this effort to fruition in time for informal yet fully functional METOC support during OIF.

II. ACQUIRING MODIS

Critical to NRL Monterey's role in the wartime support effort was its ability to field value-added products within a time window necessary for their inclusion in a variety of operational activities (including general forecast and strike brief preparation, ship navigation, and weapons selection guidance). Conversations with METOC aerographer's mates (AGs) on aircraft carriers revealed that satellite information more than 4-6 hours old is not useful from a mission planning perspective. This figure became the latency goal. The primary challenge was then determining a mechanism to obtaining the highest quality data from observing systems that were not originally engineered to serve this role (e.g., research satellites).

Among the most highly capable of satellite observing systems flying during OIF were the recently launched EOS constellation Terra and Aqua satellites, carrying among other environmental sensors the MODIS optical radiometer instruments. The Terra satellite, launched into sun-synchronous orbit in December of 1999, provided a local equatorial crossing time of 1030 (on a descending node). The Aqua satellite, launched in May of 2002, provided a 1330 local time ascending node. Each satellite was designed for a six-year mission. MODIS images 36 narrowband spectral channels situated between 0.4 to 14.4 μm . All infrared channels exist at 1-kilometer (km) sub-satellite spatial resolution, and seven visible and shortwave infrared channels provide native resolutions of either 500 meters (m; channels 3-7) or 250m resolutions (channels 1 and 2). The capabilities of these sensors to provide high-resolution and well-calibrated observations for cloud, dust, water turbidity, and many other METOC-relevant environmental parameters made the procurement of Terra/Aqua MODIS data over Southwest Asia a top priority.

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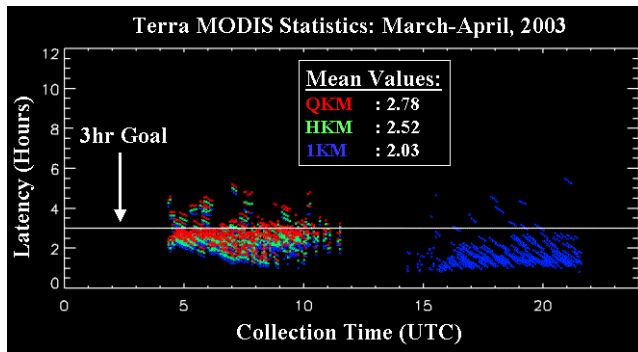


Fig. 1 Latency Statistics from the Terra-MODIS sensor for March 1 – April 30, 2003. Each point represents a five-minute “granule” for 1km (1KM), 0.5km (HKM), or 0.25km (QKM) datasets.

To this end, several DoD agencies (NRL, FNMOC, and the Air Force Weather Agency (AFWA)) joined to develop a near real-time processing capability for MODIS. In the established arrangement, global Terra MODIS data is down-linked via dual Tracking and Data Relay Satellite Systems (TDRSS), preprocessed at White Sands New Mexico, broadcast via communication satellites to Goddard Space Flight Center in Washington DC, processed to calibrated radiances, and then sent via the Defense Research and Engineering Network (DREN) to NRL in Monterey (or other customers) for the final post processing of environmental products. Optimized downlink/transfer protocols, combined with start-of-the-art hardware, software, and communication upgrades, resulted in a steadily improving (manifested in reduced latencies) capability over the development period. In the early stages of testing in Summer 2002, average latencies hovered near 6-8 hours—just beyond the window of minimal operational utility. Less than a year later and in advance of the conflict in Iraq, a series of upgrades brought daytime latencies of 2-3 hours and nighttime data inside of 2 hours (Fig 1). With optimized post-processing software developed and in place at NRL, the end-to-end system was ready to provide satellite information of unprecedented quality to the warfighter in near real-time.

III. MODIS PRODUCT EXAMPLES

The addition of MODIS telemetries enabled a quantum leap in quality and capability for several derived products as well as the creation of entirely new applications based on the previously unavailable spectral information. Direct broadcast data made available by the University of Wisconsin-Madison’s Space Science and Engineering Center (SSEC) afforded NRL the opportunity to develop algorithms in a near real-time environment over the continental United States. When data over Southwest Asia became available, these algorithms were readily ported to the new domain. The proof-of-concept demonstrated by this antecedent activity prepared the NRL team to “hit the ground running.” It also played a significant role both in justifying the pursuit of near real-time MODIS for support of the DoD and in the eventual procurement of direct

broadcast X-band receiving systems now operating at Navy Regional Centers in Bahrain and Spain.

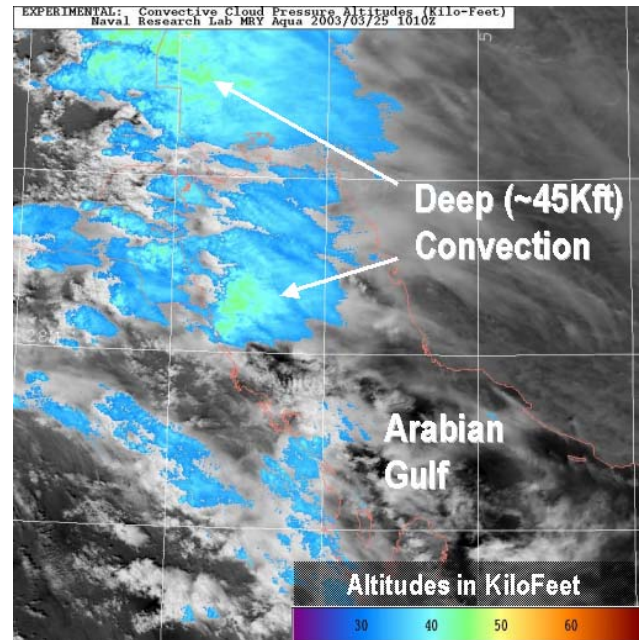


Fig. 2 Cells of deep convection cross Southern Iraq and the Northern Arabian Gulf in advance of a powerful spring storm bringing high winds, heavy rain, and thick dust.

A. Selected Product Examples

Among the many new/improved satellite applications enabled by the high spatial and spectral resolution MODIS telemetries are the following:

- i) A cloud top product (Fig. 2) flagging deep convection diagnostically (e.g., developed from [2]) and retrieving altitudes from infrared brightness temperatures mapped to numerical weather prediction model profiles.
- ii) An improved nocturnal low cloud detection product (Fig. 3; see [3]) incorporating a false-positive land background filter to remove desert surface “false cloud” contributions.
- iii) Multi-spectral-based cloud/snow discriminators (Fig. 4) to decouple low/high clouds from snow-covered backgrounds, with improvements to cirrus filtering by virtue of the MODIS 1.38 micron channel (e.g., [4]).
- iv) Significant dust enhancements over land and ocean (Fig. 5) based on a new multi-spectral technique for MODIS [5].
- v) Aircraft contrail enhancements using tri-spectral infrared measurements (Fig. 6).
- vi) High-resolution (250m) true color imagery zoomed over specific areas of interest (Fig. 7).

In the race to develop and implement a multitude of beta-level algorithms in advance of the Iraq conflict, it is only now in the post-war environment that many of these techniques are enjoying the luxury of refinement and

formal documentation. The immediate and significant impacts to METOC operations during OIF, afforded by this somewhat regressive approach to traditional protocols of research and development, could be justified only in context of the calls for assistance raised during this unusual time of high need.

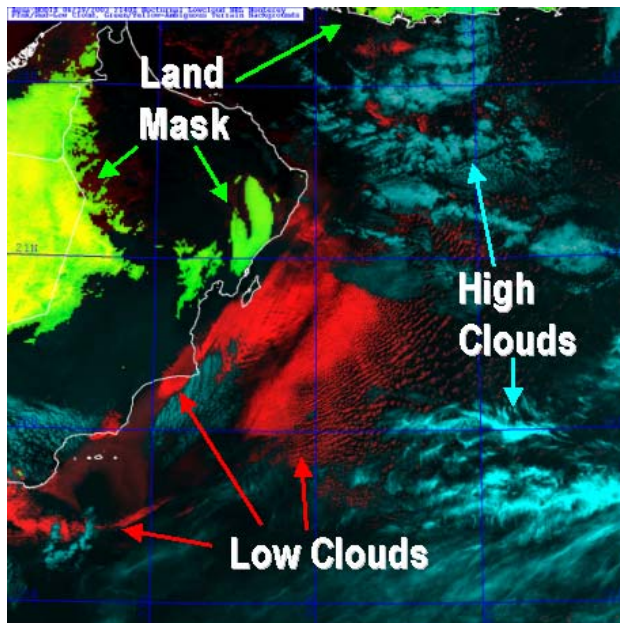


Fig. 3 Nocturnal low cloud product developed with low clouds as red, high clouds as blue, and false-positive land surfaces as green/yellow (would otherwise appear red).

B. Product Distribution

These and other products developed from a constellation of available polar-orbiting and geostationary environmental satellites formed the basis for the NRL Satellite Focus Web Page [6]. With a highly portable, dynamic, nested architecture, and user-friendly design, Satellite Focus was designed to serve as a consolidation of co-registered satellite applications over domains of high interest. The effect is to provide users with “one-stop shopping” and reduce their need to search amidst a myriad of disparate sources. With access to a global suite of satellite information and numerical weather prediction fields in near real-time, new areas of focus can be initiated anywhere on the planet at a moment’s notice. The resource includes online training, customized animation, and satellite pass prediction for each of the available telemetries and products.

To accommodate the bandwidth limitations of many DoD customers, Satellite Focus is hosted as a beta application on the FNMOC secure internet operational web page. The imagery feeding this website serve as building blocks to other FNMOC products, including a desert dust discussion tailored for the Southwest Asia domain.

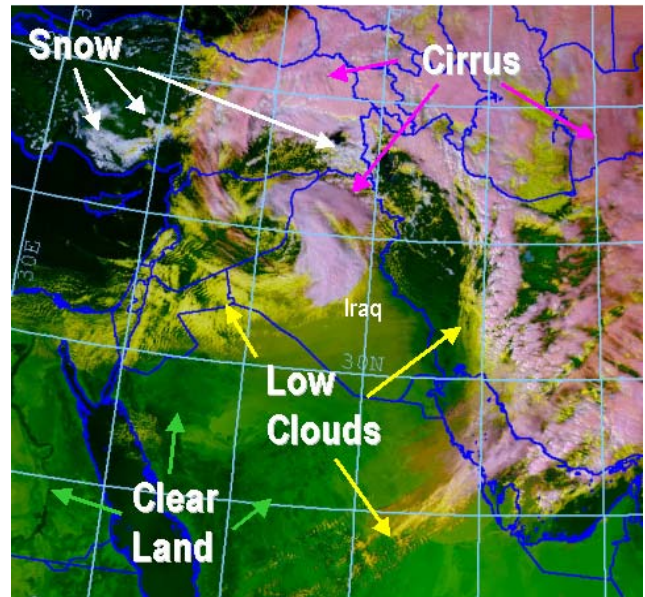


Fig. 4 High/low cloud and snow discriminator product displays low clouds and high clouds as yellow and magenta, respectively, while snow appears white and snow-free land surfaces are green.

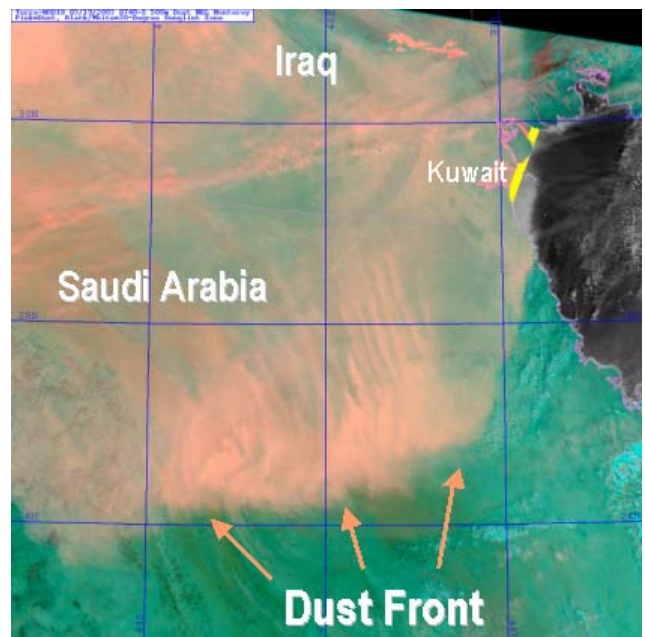


Fig. 5 Heavy dust, enhanced as orange/pink against a green land background, drifts southward across Kuwait and Saudi Arabia. Of all the MODIS products fielded in support of OIF, the dust enhancement was most routinely used.

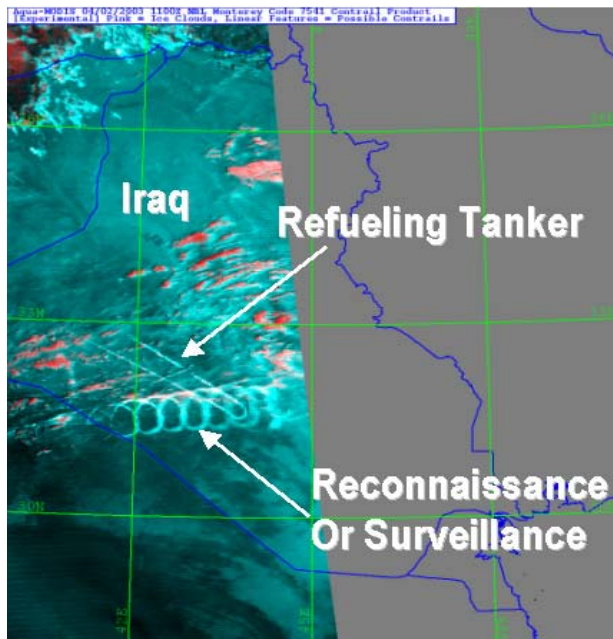


Fig. 6 Enhancement capturing optically thin aircraft condensation trails (contrails) as bright linear features against relatively dark backgrounds.

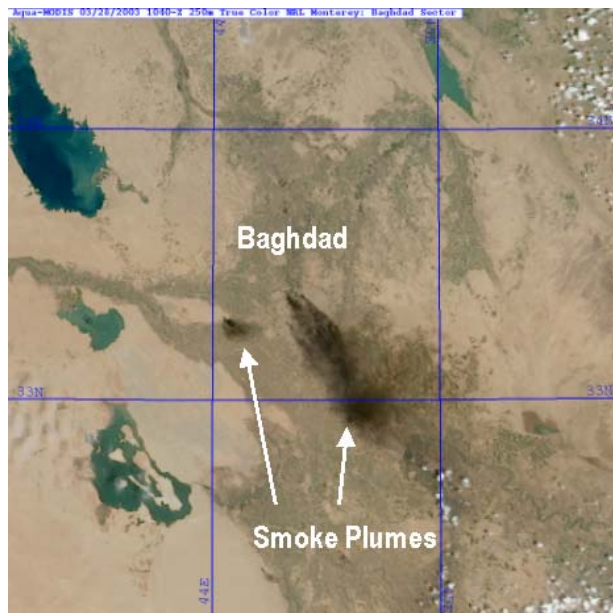


Fig. 7 Smoke plumes issue from both bomb/missile destruction and oil trench fires set by the Republican Guard drift to the southeast in this 250m-resolution true color product over the city of Baghdad.

IV. USER FEEDBACK

The most convincing testimonials to the impact and success of the overall effort of course come from the customers themselves. Through correspondence with DoD personnel at Prince Sultan Air Base, Ramstein Air Base,

NCMOC Bahrain, and aboard aircraft carriers deployed in theater, NRL scientists were able to gauge the utility of the products while providing important web page orientation and product training for the new users. The following excerpts shed light on the relevance to the fleet of the MODIS products hosted on Satellite Focus, and some of the ways in which they were used in actual decision-making scenarios during OIF. Clarifying text has been included in [brackets] where applicable:

AGC Steven Cole, USS KITTY HAWK:

"We check the [Satellite Focus] website twice per day...thank you for the support, it has been helpful to us out here."

"Dust has prevented the use of laser guided munitions, and I have been depicting [MODIS dust products] in my slides to the embarked AirWing."

"We use the [MODIS dust product] to monitor dust events over Iraq and the NAG and it is an awesome product."

AG2 Anthony Wade, USS ABRAHAM LINCOLN:

"The forecasters are using the [MODIS] products every day; they have increased the ship and battle group's capability to anticipate weather impacts."

"We used the [MODIS] dust imagery to brief the Desron Commander on the situation in the Northern Arabian Sea. Products are very useful and will be mentioned and the NRL/FNMOC credited in lessons learned and end of cruise report."

"We used the products in 85% of strike briefs and 100% of forecasting. Strike plans were altered and set using some NRL products. I can not thank you enough for the products provided for this deployment."

[During a heavy dust outbreak, March 25-27]:

"Navy ships are taking over all operations in support of ground troops and bomb runs. All ships are receiving aircraft from others as well. We are currently using the [Satellite Focus] products to determine the Abe's track to safely support the mission."

The examples above are a small but representative sample of the feedback received. Additional information pertaining to product validation and detailed application of the imagery within the scope of pilot reports and strike briefs were very useful to the NRL development team. During the period of active combat in OIF (roughly, March 19 – April 9, 2003), NRL scientists worked literally around the clock to ensure processing system health, updated telemetries, and provide online support via secure e-mail chat with users deployed throughout the theater. The difficult task of quantifying the impact of this contribution in terms of dollars and lives saved due to modified weapons selection, target selection, strike planning, and mishap avoidance is now underway.

V. FUTURE DIRECTIONS

While attaining 2-3 hour latencies is a dramatic achievement when considering the task at hand and the timeline set for its implementation, the operational scope and utility of these data continue to increase exponentially toward real-time collection. Selected products (high resolution true color and dust enhancements) were forward deployed to NCMOC immediately prior to the onset of OIF for real time support for implementation on their newly acquired X-band direct-broadcast system (where products become available only minutes after observation), while others were relegated to the near real-time Satellite Focus effort. As these latter products develop according to user feedback and algorithm advances/validation, they will also be incorporated into the center's routine processing schedule. Ongoing rapport with deployed personnel using the products to support their missions will continue to ensure a legacy of awareness for this valuable resource.

VI. SUMMARY

This paper describes efforts at NRL Monterey to play a pseudo-operational role in the production of high quality near real-time MODIS applications for direct support of DoD assets during Operation Iraqi Freedom. The turnaround for these products is generally within 2.5 hours of initial data collection. Concurrent development of new web interface technology for intelligent product dissemination on secure internet bandwidth (Satellite Focus Web Page) formed a new and potentially powerful resource for the METOC community. Direct feedback from satisfied users speaks volumes to the positive impact these products made during the OIF conflict. At the same time, this interaction benefits developers through constructive suggestions for improving product relevancy and functionality to the Fleet. For this reason NRL will maintain a pseudo-operational involvement within this symbiotic paradigm for developing new products, while toward transitioning mature applications to chartered operational facilities to ensure formal 24/7 support.

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